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**Nuno Boavida**

(e-mail: [nuno.boavida@campus.fct.unl.pt](mailto:nuno.boavida@campus.fct.unl.pt))

**Manuel Baumann**

(e-mail: [nuno.boavida@campus.fct.unl.pt](mailto:nuno.boavida@campus.fct.unl.pt))

**António Moniz**

(e-mail: [nuno.boavida@campus.fct.unl.pt](mailto:nuno.boavida@campus.fct.unl.pt))

**Jens Schippl**

(e-mail: [nuno.boavida@campus.fct.unl.pt](mailto:nuno.boavida@campus.fct.unl.pt))

**Max Reichenbach**

(e-mail: [nuno.boavida@campus.fct.unl.pt](mailto:nuno.boavida@campus.fct.unl.pt))

**Marcel Weil**

(e-mail: [nuno.boavida@campus.fct.unl.pt](mailto:nuno.boavida@campus.fct.unl.pt))

## **Technology transition towards electric mobility – Technology Assessment as a tool for policy design**

**IET/CESNOVA**

**Enterprise and Work Innovation pole at FCT-UNL**

**Centro de Estudos em Sociologia**

Faculdade de Ciências e Tecnologia

Universidade Nova de Lisboa

Monte de Caparica

Portugal

# **Technology transition towards electric mobility**

## **– Technology Assessment as a tool for policy design – <sup>1</sup>**

**Nuno Boavida<sup>1,2</sup>;**

**Manuel Baumann<sup>1,2</sup>;**

**António Moniz<sup>1,2</sup>;**

**Jens Schippl<sup>1</sup>;**

**Max Reichenbach<sup>1</sup>;**

**Marcel Weil<sup>1,3</sup>**

<sup>1</sup>Karlsruhe Institute of Technology (KIT), Institute for Technology Assessment and System Analysis (ITAS)

<sup>2</sup>Universidade Nova de Lisboa, Centre for Sociology Studies (CESNOVA/IET)

<sup>3</sup>Helmholtz-Institute Ulm for Electrochemical Energy Storage (HIU)

### **Abstract:**

The paper aims to understand the degree of transition towards e-mobility. The assumption is that the degree of convergence between actors of each system (batteries, vehicles, grid, policies, business models and consumers) is an indicator of changes in the present socio-technical regime. After an

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introduction to the socio-technical transition towards e-mobility, the paper presents and discusses three technology assessment approaches to several projects related to technology, society and politics.

There are several thematic crossovers between all projects presented leading to a synergetic technology assessment. This output results from the overlapping areas between the cases and can be used to first assess the extent of changes in the present socio-technical regime, as well as to extract standards and regulations, acceptance/risk analyses and behaviour changes that could be significant in the context of a transition towards electric mobility.

**Keywords:** Electric mobility, Electric vehicle, Technology Assessment; Batteries, Policy design

**JEL codes:** O31, R41, R48

# 1. Introduction

Analysts agree that a technology shift towards electric mobility could help decoupling transport growth from negative environmental impacts, improve fuel consumption and deal with the increasing demand for individual mobility in a more sustainable way. Four main factors are critical to understand the changes occurring in this e-mobility shift: batteries and vehicles, infrastructures (e.g. grids, charging infrastructure), new business models (e.g. car sharing, battery leasing, power grid services) and people's behaviour (Fournier et al. 2010; Fournier 2012). Furthermore, the technological transition will also increase the complexity present in transport systems through a rise in the number of actors (newcomers, users in their active role, power companies, etc.) and the diversification of stakeholders (energy providers, new service providers, etc) (Schwedes et al. 2012). Their complex interactions require a prospective and systemic perspective to better anticipate and govern the developments in e-mobility.

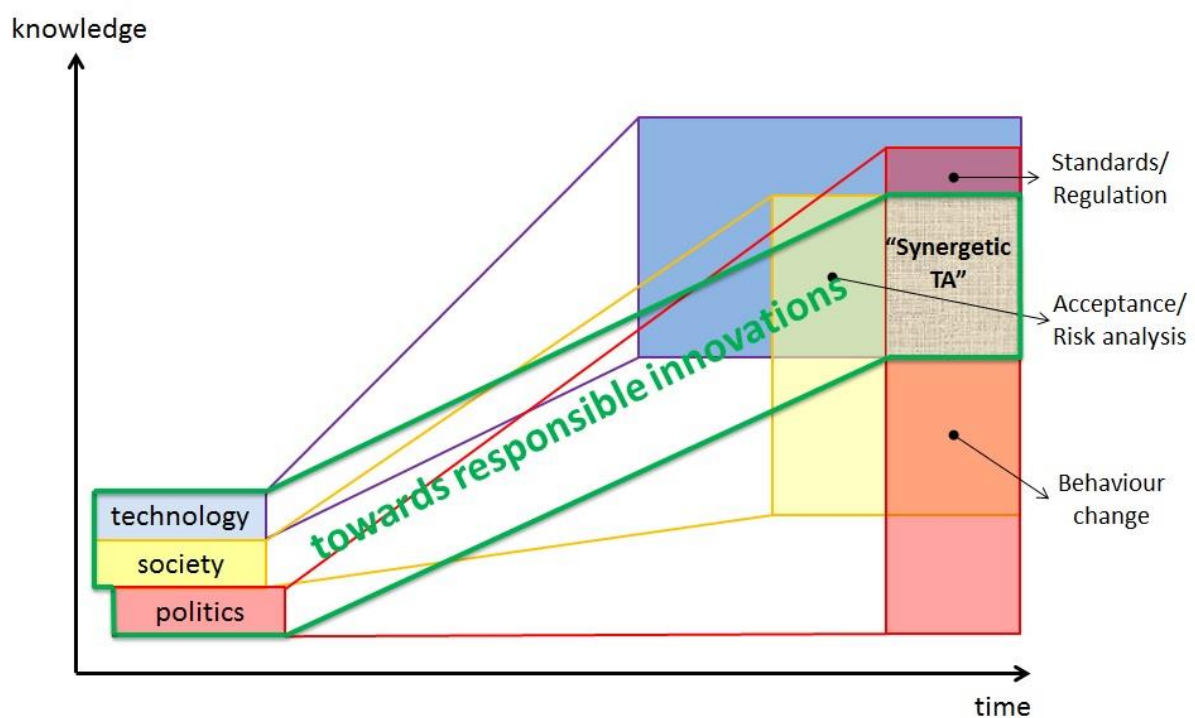


Figure 1 - Synergetic Technology Assessment approach

This work presents three technology assessment approaches with such perspective (see Figure 1). The different approaches differ according to the main interest of the research projects. But they all apply broader, systemic perspectives in a problem oriented manner. Such an approach is needed to be able to say something on the convergences of visions and future technology transitions.

In this context, the paper aims to understand the degree of transition towards e-mobility. The assumption is that the degree of convergence between actors of each system (batteries, vehicles, grid, policies, business models, consumers), is an indicator of changes in the present socio-technical regime.

In the first chapter the paper briefly revisits the history, relevance and transition context of e-mobility, to frame the understanding of present and future trends in electric mobility. In the following chapter, the article presents three technology assessment approaches towards e-mobility cases. The first case presents results from the AutoSuperCap European project, and the German projects ProSyBatt and Portfolio (Weil 2012). The second of the case studies is related the policy developments during the launching of the Portuguese public charging network Mobi-E in Portugal. The third and last approach relates to several cases in Germany and to projects conducted by the authors for the STOA<sup>2</sup> panel of the European Parliament. Last, the article presents conclusions and discussion on the encompassing effects of applying a prospective and systemic perspective to better anticipate and govern the developments in e-mobility.

## **2. Electric mobility**

### **2.1 A brief history of electric mobility**

The history of the electric mobility dates back to the early 19th century, when inventions in the field of electrical science were very frequent (Doppelbauer 2013). Frequently, the inventors worked in national contexts and knew nothing about each other's work. In fact, many inventors were working worldwide and in parallel on the invention of an electric propulsion mechanism to propel various types of vehicles. An overview of the development of electric vehicles in combination with exogenous influence factors is given in figure 2 and is explained in the following.

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<sup>2</sup> Science and Technology Options Assessment

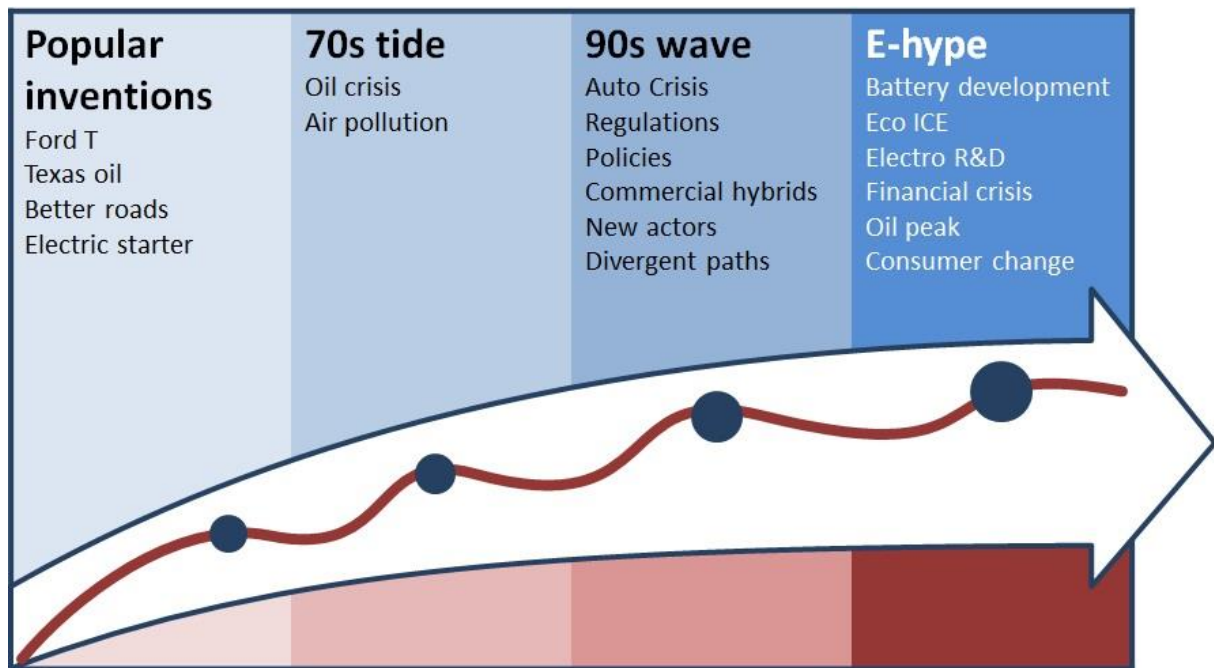


Figure 2 - Evolution of e-mobility

The origins of the electric vehicle (EV) are often traced back to the year 1827, when the Slovak-Hungarian Benedictine priest Ányos István Jedlik built the first crude but viable electric motor (Heller 1896; Guarnieri 2012; Chan 2013). One year later, Jedlik invented a small-scale car powered by an electric motor. Sibrandus Stratingh presented another small-in scale electric car in 1835, built by his assistant Christopher Becker (Chan 2013). Other inventors were also credit with similar inventions, such as Robert Anderson, Thomas Davenport and Charles Gafton Page (Guarnieri 2012).

According to Chan (2013), in the mid-19th century, EVs were very popular because they were seen as clean, quiet and easy to start. The author reports that in the beginning of the 20th century, electric cars reached their highest success ever, conquering 38% of the market, although 40% belonged to steam engines and 22% to gasoline propelled cars. However, the growing interest on these vehicles eventually started to decline. In fact, in the US the decline was propped by the introduction of the cheaper internal combustion engine vehicles (e.g. Ford T), improved road system and the need for longer driving ranges, the discovery of Texas oil and the invention of the electric starter (Chan 2013).

The second interest in EVs re-emerged in the 1970s, mainly due to the effects of rising oil costs and air pollution. Chan (2013) related this revival mainly to the oil crisis in the Middle East. But, at the end of the 1970s, less than 4000 EVs had been sold in the world (Dijk et al. 2012).

A third popular wave occurred in the early 1990s, bringing renewed hopes that EVs would be sold to mass markets. According to Schwedes et al. (2012), these hopes were a consequence of the impact of the economic crisis in the automotive industry. Furthermore, Dijk et al. (2012) and Schwedes et al.

(2012) agreed that other events prompted this third hype, such as the effects of the regulatory push created by the Californian Zero Emission Vehicle Program and, to a lesser extent, the environmental policies (Chan 2013) and programs promoted in Europe.

During this period, several e-car initiatives failed to produce the expected effects. For example, according to Dijk et al. (2012) the French electric utility experimented with 2000 EV in La Rochelle and, as expected, although users “loved” EVs, only a few consumers were willing to buy the new car. The authors reported also that the lobbying efforts of the auto industry in California and in Europe contributed to hold back any commercial success of EVs. In fact, although there were electric vehicle associations in the US, Europe and Easter-Asia, public support was not able to counterbalance this industrial lobby.

The efforts of the automotive industry in the 1990s were weakened by the growing importance of the power industry and the emergence of new actors, as Schwedes et al. (2012) remarked. In fact, as new players entered the field of electric mobility, old automotive actors pursued different paths. On one hand, the Japanese Toyota and Honda were the first to move towards the commercialization of electric vehicles, launching in the end of the decade the first versions of hybrids: Prius<sup>3</sup> and Insight, respectively (Dijk et al. 2012). On the other hand, disappointing experiences of other car makers (e.g. Volkswagen’s Lupo 3l) led most Original Equipment Manufacturers (OEMs) to believe there was no profitable market for fuel-efficient cars (Dijk et al. 2012).

The fourth hype began in 2005, when there was a small shift in the perception of constructors regarding the kind of cars consumers would be willing to buy. In fact, most car manufacturers invested considerable resources in R&D to catch up. However, Schwedes et al. (2012) describes the emergence of this fourth hype based not just on a bigger awareness to climate change and the necessity of countermeasures. In fact, the authors considered also the impacts of the 2007’s financial and economic crisis, higher oil prices and the expected shortage anxiety (after reaching the oil peak), as well as strong technical developments in the field of battery technology. Nevertheless, the hype occurred in a context where most companies had invested heavily in refining the internal combustion engine and decided instead to sell ‘eco’ versions of old models (e.g. Volkswagen’s Bluemotion technology) (Dijk et al. 2012). Therefore, it can be concluded that although a small shift was detected in the traditional industrial perception on the needs of buyers around the world, reality showed an emphasis on higher fuel efficiency rather than on electric motors.

In this context, it can be said that the history of electric mobility has been linked with the invention of technologies responsible for propulsion, such as the electric motor, the ICE<sup>4</sup> and batteries. The availability of resources played also an important role, such as financial or raw materials. A third element to take in to account is the influence of actors, like governments, lobbies, consumers, etc.

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<sup>3</sup> According to Dijk et al. (2012), the sales of the hybrid Toyota Prius, reached more than 3 million vehicles from December 1997 to March 2011 in total (Toyota Motor Corporation, 2011).

<sup>4</sup> Internal combustion engine

The development of e-mobility strategies pushes also other sectors towards innovation processes to respond new business challenges. Examples can be shown not only from the OEMs of the automotive industry, but also from the different components (batteries and power systems). However, this component sector is also contributing to other industries, like the railway sector, bicycle industry, even household energy storage. The e-mobility infrastructure does not apply only to the road or rail structures, but also to energy providing management systems, and to intermodal processes.

This means that e-mobility is far beyond just automotive industry, but includes an all set of business functions and a development of several value chains. For example, energy production and distribution, transport services, vehicles manufacturing and recycling, and integration of parts of those different chains. The social and economic implications are clear.

## **2.2 Why is e-mobility relevant?**

The technological advance and changing consumer perceptions are gradually raising the popularity of electric powertrains. One of the reasons is because users become more environmentally conscientious, and the price of traditional combustion engine fuels continues to rise as depicted in figure 4.



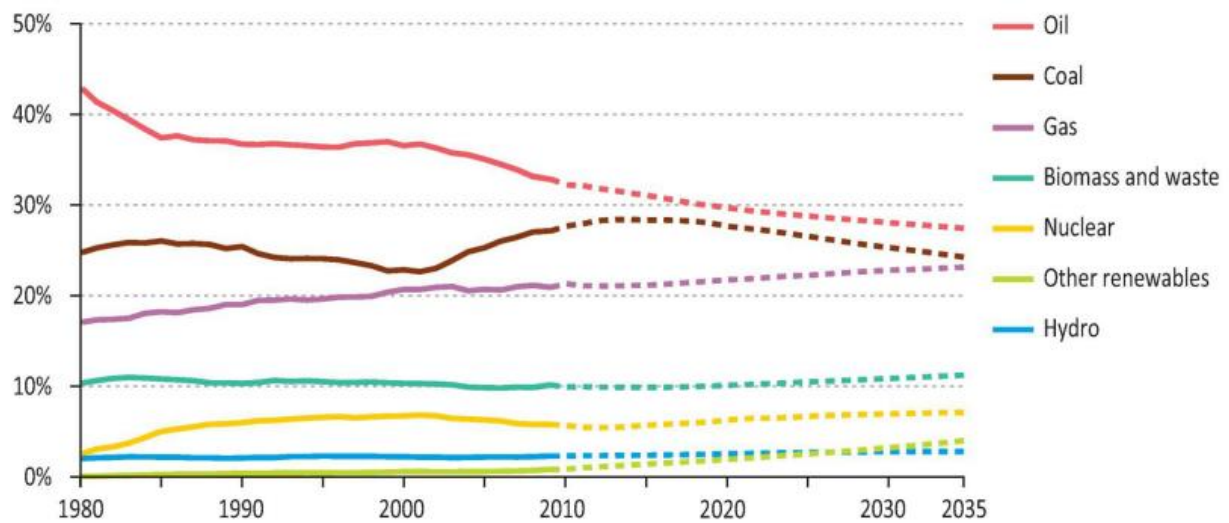


Figure 4: Shares of energy sources in world primary energy demand

Source: IEA, World Energy Outlook 2011

As mentioned in World Energy Outlook 2011, all of the net increase in oil demand comes from the transport sector in emerging economies, as economic growth pushes up demand for personal mobility and freight. Oil demand (excluding biofuels) rises from 87 million barrels per day (mb/d) in 2010 to 99 mb/d in 2035. The total number of passenger cars doubles to almost 1.7 billion in 2035. Sales in non-OECD markets exceed those in the OECD by 2020, with the centre of gravity of car manufacturing shifting to non-OECD countries before 2015 (OECD/IEA, 2011:41).

The rise in oil use comes despite some impressive gains in fuel economy in many regions, notably for passenger vehicles in Europe and for heavy freight in the United States. Alternative vehicle technologies emerge that use oil much more efficiently or not at all, such as electric vehicles, but it takes time for them to become commercially viable and penetrate markets. With limited potential for substitution for oil as a transportation fuel, the concentration of oil demand in the transport sector makes demand less responsive to changes in the oil price (especially where oil products are subsidised), continues the IEA report (OECD/IEA, 2011:41).

The European Commission advocates a ban on conventional vehicles from city centres by 2050. According to ACEA an EU-level sustainable urban transport policy needs to meet the needs of all cities and this is challenging because Europe's urban areas differ greatly. Traffic is a basic requirement of cities in which economic activities are carried out. Any measures that are implemented need to have clear and measurable objectives and have to follow the principles of better regulation and cost-

effectiveness. It is very important that authorities that decide to implement access restrictions have a vision for mobility and have a strategy that is not static but subject to regular monitoring and periodic reviews. Restrictions should have a clear objective and be removed as soon as the objective is reached. Unfortunately local authorities in the EU have approached access restrictions with an array of mainly un-harmonised measures, which are increasingly creating difficulties for both local and international businesses. The transport behaviour of citizens depends on their transport needs and this depends on how the land and cities are organised. Focusing solely on electrically chargeable vehicles in city centres does not solve the real urban problem – congestion.

This association also refers that “most stakeholders assume a realistic market share for new electrically chargeable vehicles to be in the range of 2 to 8% by 2020 to 2025, based on today’s market. This depends on how quickly some of the immediate challenges can be addressed by industry and upon a number of external factors (e.g. infrastructure and support by utility providers and governments)” ([http://www.acea.be/news/news\\_detail/frequently\\_asked\\_questions\\_on\\_e-mobility/](http://www.acea.be/news/news_detail/frequently_asked_questions_on_e-mobility/)).

The argument is very interesting on the future trends in terms of industrial production of electric vehicles in Europe. The “EU vehicle manufacturers are world-wide technology leaders in fuel efficiency and safety. Electrically chargeable vehicles provide the opportunity for further EU leadership in engineering and also can encourage the competitiveness of the sector (e.g. further research and innovation), with a potential positive impact on employment in the EU also in other related sectors” (idem).

A structural change is likely to occur in the medium-term, and which will have a significant impact on the relative utilisation of capital and labour. The exact format of the paradigm shift is, as yet, unknowable. Any change is likely to have an impact on economic growth, particularly if there is a shift away from production in Europe. Supportive policies from governments for battery production and battery technology research can help to keep this part of the value chain in Europe.

In the Energy Outlook 2030 exercise made by BP, the forecast use of energy in transport is the as depicted in figure 5.

## Energy in transport

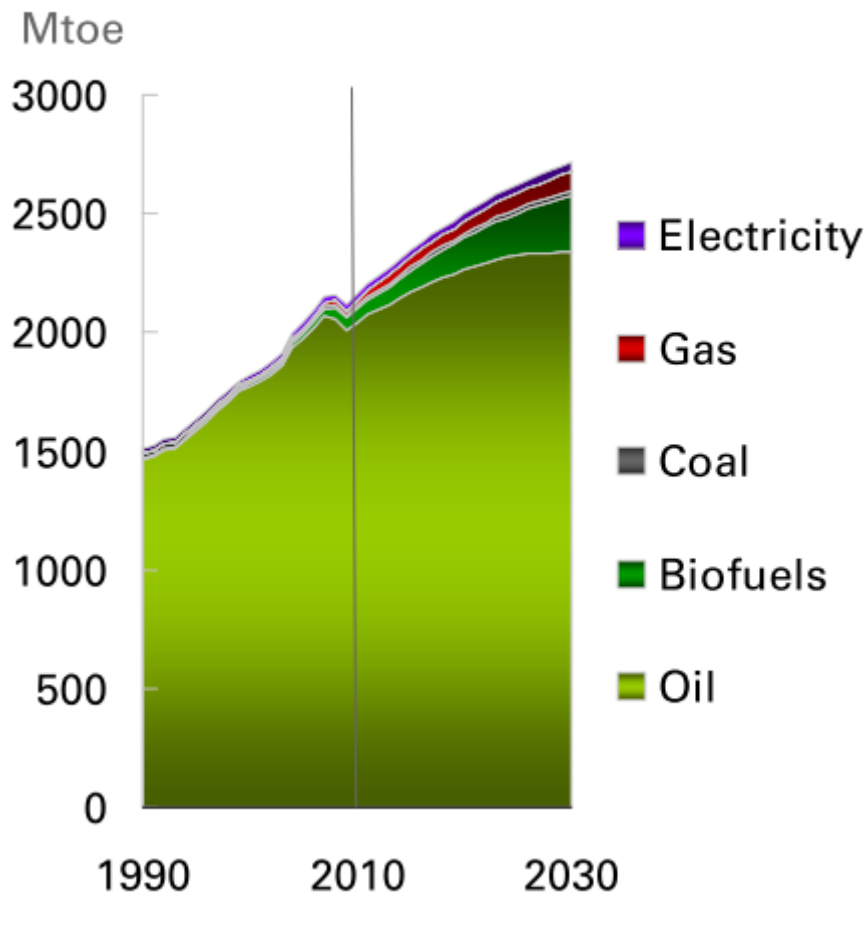
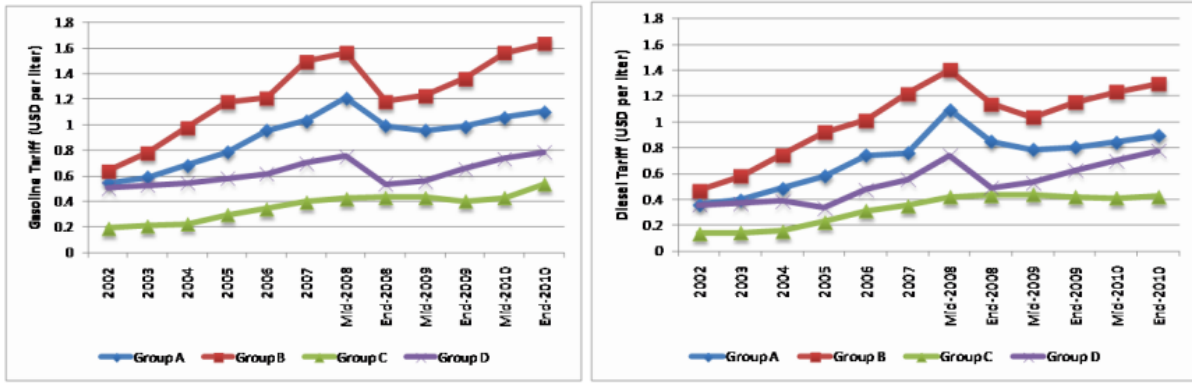


Figure 5: Energy in transport

Source: BP, 2011:30

Energy used for transport will continue to be dominated by oil, but should see its share of global energy use decline as other sectors grow more rapidly. According to BP the growth of oil in transport slows even more dramatically, largely because of displacement of oil by biofuels and is likely to plateau in the mid-2020s. Currently, biofuels contribute 3% on an energy basis and this is forecast to rise to 9% at the expense of oil's share. Rail, electric vehicles and plug-in hybrids, and the use of compressed natural gas in transport is likely to grow, but without making a material contribution to total transport before 2030.

However, according to World Bank statistics, the oil prices for transport are increasing in the last years as shown in figure 6.

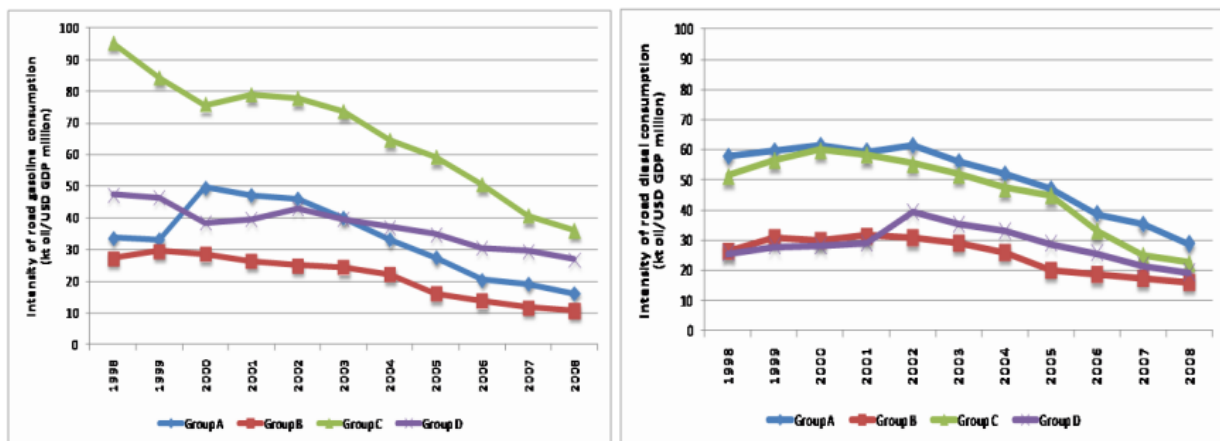


Source: World Bank (2011)

Figure 6: Fossil fuel prices over time

Source: World Bank (2011)

A consequence is a clear decrease in fossil fuel road consumption over time as can be seen in the following figure 7 (IEA, OPEC, OECD and World Bank, 2011).



Source: World Bank (2011)

Figure 7: Fossil fuel road consumption

Source: World Bank (2011)

Their orientation is towards rational transport alternatives. Electrically chargeable vehicles (depending on the powertrain and infrastructure) will often have a well-to-wheel emissions advantage over standard combustion vehicles, which appeals to environmentally friendly users. Further, with new technology it is now possible to partially overcome the range limitations which previously made the electrically chargeable vehicles undesirable.

As a result of continuous investment by the industry over decades, and through recent breakthroughs in battery technology, electrically chargeable vehicles are now suitable to enter the market in larger numbers than in the past.

According the World Energy Outlook from IEA, “total electricity generation from renewable sources increases from 3 900 TWh in 2009 to 11 100 TWh in 2035, its share of total generation growing from 19% to 31%. Throughout the Outlook period, hydropower is the largest renewable source of electricity generation. Electricity generated from wind power increases by nearly ten-times over the Outlook period, reaching 2 700 TWh in 2035. China’s consumption of electricity generated from wind power surpasses that of the European Union soon after 2030. Solar generated electricity (solar PV and concentrating solar power [CSP]) sees strong growth globally, particularly in the second half of the Outlook period, and reaches 1 050 TWh in 2035. Global electricity generating capacity using renewable sources increases from 1 250 GW in 2009 to 3 600 GW in 2035 (OECD/IEA, 2011:86).

Road transport demand continues to dominate in the transport sector, representing 75% of demand in 2035. Oil demand in the road transport sector increases by 32% over the Outlook period, from 35 mb/d in 2009 to 45 mb/d in 2035. While many countries have adopted fuel efficiency standards, the growth in demand in non-OECD countries more than offsets the effect of these improvements. The global stock of road transport vehicles nearly doubles between 2009 and 2035, but the adoption of stronger efficiency standards, a shift in market focus toward non-OECD countries with lower average vehicle usage levels and, to some extent, the increased use of alternative vehicle technologies, means that the increase in energy demand is only around 42%. While the picture improves, the penetration of electric vehicles remains relatively small globally in 2035 (OECD/IEA, 2011:87).

The variation in world level on the number of passenger light-duty vehicles (PLDV) per thousand people by region, comparing the years 2009 and 2035 (projection), and the change in oil demand in road transport is visible in the following figure 8.

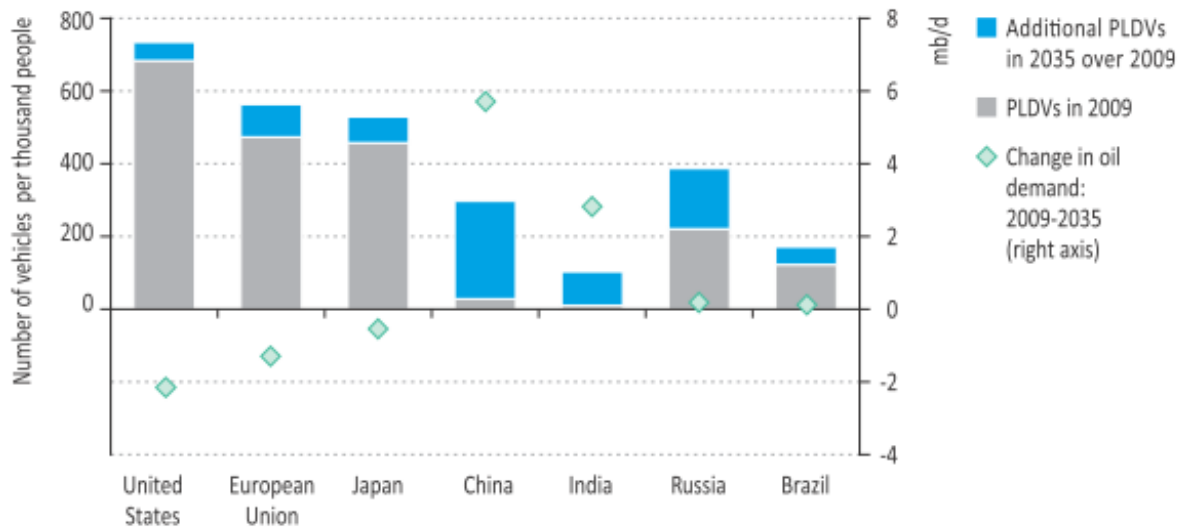


Figure 8: Number of passenger light-duty vehicle (PLDV) per thousand people by region, 2009 and 2035, and the change in oil demand in road transport

Source: OECD/IEA, 2011:88

Vision 2020: The research and development undertaken by German research institutions and industry sets the benchmark for electric mobility innovation worldwide (GGEMO, 2012:16).

## 2.3 Sociotechnical transitions

The present developments can be understood within the framework of sociotechnical transitions, and analysed in the context of niche-innovations with structured activities of small networks of actors. According to Geels & Schot (2007), some players support novelties on the basis of expectations and visions, and conduct efforts to link different elements in a unified web. The history of the electric vehicles reflects some of this support towards the emergence of electric motors, electric trams and electric cars, etc (Guarnieri 2012; Geels & Schot 2007; Chan 2013). Furthermore, present developments can be analysed as a move to combine different novelties by several stakeholders: policy pushes; the commercialization of electric vehicles by Nissan, Mitsubishi, BYD and Tesla, among others (IEA 2011).

However, to consider a serious sociotechnical transition to electric mobility, these niche-innovations around electric technologies need to be aligned and stabilised in a dominant design, increasing their

internal momentum. In fact, the present dominant technology is still largely the Internal Combustion Engine (ICE), regardless of actual developments on electric vehicles, several hybrids, batteries, etc.

Furthermore, niche-innovations need to be a part of a bigger structured movement interacting not only with the movements of their socio-technical regime but also with pressures from the socio-technical landscape. As seen before, the industrial perception captured consumer's desires to move towards "greener" technologies. However, most OEMs preferred to remain with the old technological regime, regardless the landscape slide towards de-carbonization of mobility. The engine of the T-Ford model of 1908 is still the dominant design, although hybrids may be gaining internal momentum. In fact, the rising numbers of sales among hybrid models might be seen as niche-innovation pressure that can lead to major regime tensions if coupled with other landscape developments (e.g. citizens' perception and attitudes, political pressures, etc).

Schwedes et al. (2012) argued that the success and failure of technological innovations largely depends on political decisions, more than on the contents of the discourse or the actors involved in supporting it. However, Chan (2013) sustained that involvement of stakeholders are crucial to the success of EVs. In this paper it will be argued that political decisions are but a part of a bigger problem. Furthermore, it will be reasoned that Y. Last, the article will show that Z is true.

### **3. Technology assessment views on e-mobility**

As mentioned in the beginning, this paper aims to understand the degree of transition towards e-mobility. The assumption is that the degree of convergence between actors of each system (policies, batteries, vehicles, grid, business models, consumers), is an indicator of changes in the present socio-technical regime. The following sub-chapters present three technology assessment approaches different according to the main interest of the research projects. They all apply broader, systemic perspectives in a problem oriented manner, enabling a different look into the convergences of visions and the future technology transitions.

#### **3.1 System analysis of new battery systems for mobile and stationary applications**

The technology transition towards electric mobility leads to an increased demand of electrochemical energy storage technologies. They are the base for a future orientated mobility with electric propulsion systems including hybrid vehicles, full electric vehicles as well as hydrogen and fuel cell powered vehicles. The development, production, use, profitability and disposal of these electrochemical energy storage technologies have a major importance for a sustainable development and must be co-considered in the socio-technical conversion of our mobility as well as energy transition process.

A main drawback of battery systems is their relatively low range in relation to conventional internal combustion engine vehicles. These results from relatively low energy densities of electrochemical energy storage systems only achieved 1 % to 2 % of conventional liquid fuels. In other terms: to realize a range of 500 km a battery with a weight of 750 kg is needed (VDE 2010:9). The battery is the central and most expensive component of electric vehicles in all forms. However, beside the energy density, power density and weight, the cycle and calendar life time, safety and costs aspects are serious issues, which hinder presently a broad market penetration of battery driven electric vehicles. Systems analytical analyses are conducted for different electro chemical energy storage technologies, with different development stages and different goals (Figure 9). Beside synergetic effects between the projects, the consideration of different development stages allows the development of an integrated approach covering all areas of basic and applied research.



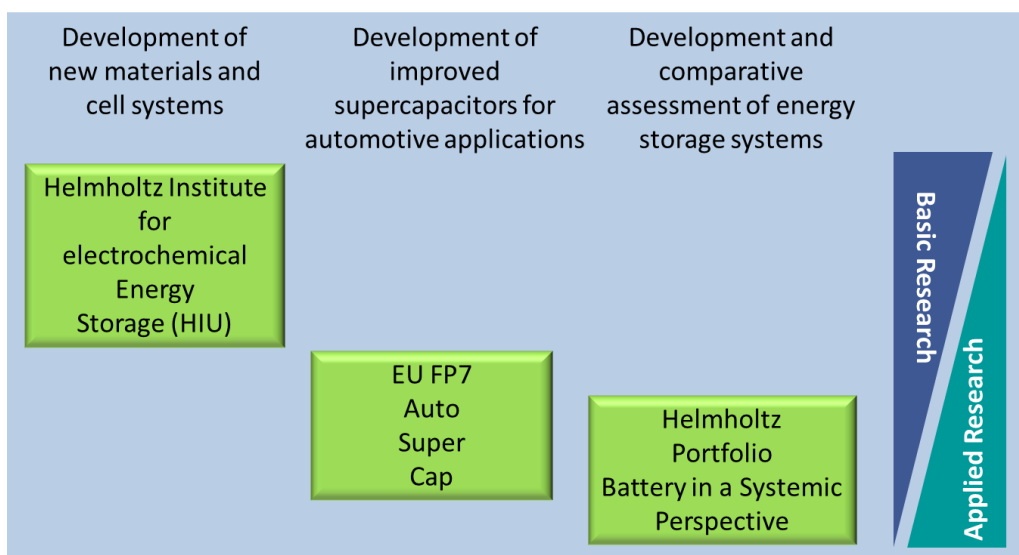


Figure 9: Contribution to new research organizations and projects regarding the development of new batteries for mobile and stationary applications

The question is how this projects support the Technology transition towards electric mobility and how they can serve as a Technology Assessment as a tool for policy design? This will be analysed in the following chapters where the projects shown in Figure 9 will be briefly introduced.

### 3.1.1 HIU

The recently founded Helmholtz Institute Ulm (HIU) is organized by Karlsruhe Institute of Technology (KIT), member of the Helmholtz Association, in cooperation with Ulm University. Associated partners are the German Aerospace Center (DLR), also member of the Helmholtz Association, and the Center for Solar Energy and Hydrogen Research Baden-Wuerttemberg (ZSW).

The HIU highly integrates the knowledge and experience of KIT and Ulm University as two leading, german academic research organisations in the field of materials science and electrochemistry respectively. The ZSW and DLR are two internationally active research organizations strongly committed to the industrial development of energy storage systems. The major goals of HIU are the conduction of fundamental and applied research on the electrochemical energy storage for mobile and stationary applications. Furthermore it an effective mechanism of technology transfer of the technological advances obtained from the research to practical applications will be developed<sup>5</sup>. The HIU focus on new high performance cell systems, which are fare beyond traditional Ni-MH (e.g. in Toyota Prius) or even Li-Ion cell systems, like e.g. Li-Air, Li-Sulfur, or Li/FeFx. Figure 10 gives an overview of the gravimetric (per mass unit) and volumetric (per volume unit) energy density (energy that can be stored within a battery) of different battery systems. It can be clearly seen, that there is a

<sup>5</sup> <http://www.hiu.kit.edu/>

high research and development potential for electrochemical energy storage technologies in mobile and stationary applications.

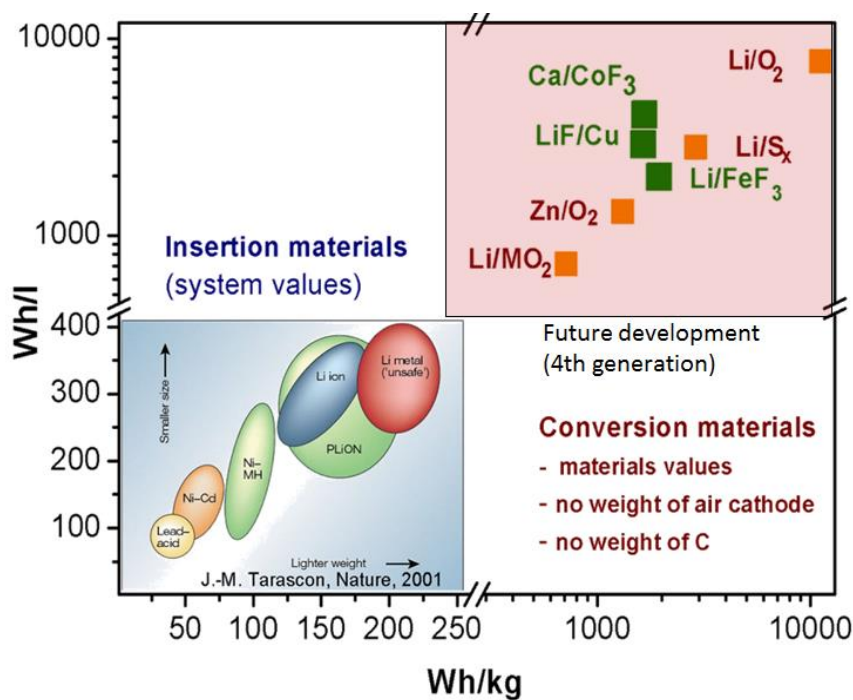


Figure 10: Overview of current (blue) and future (red) battery systems

Source: Fichtner, 2011

Within HIU there are 5 working areas (Figure 10). Two of them (Electro-chemistry, Theory) focus exclusively on fundamental research. Also a major part of the working areas Materials and Methods (development of analytical *insitu* investigations) can be allocated to fundamental research. Thus almost only the working area Systems is dedicated to more applied research.

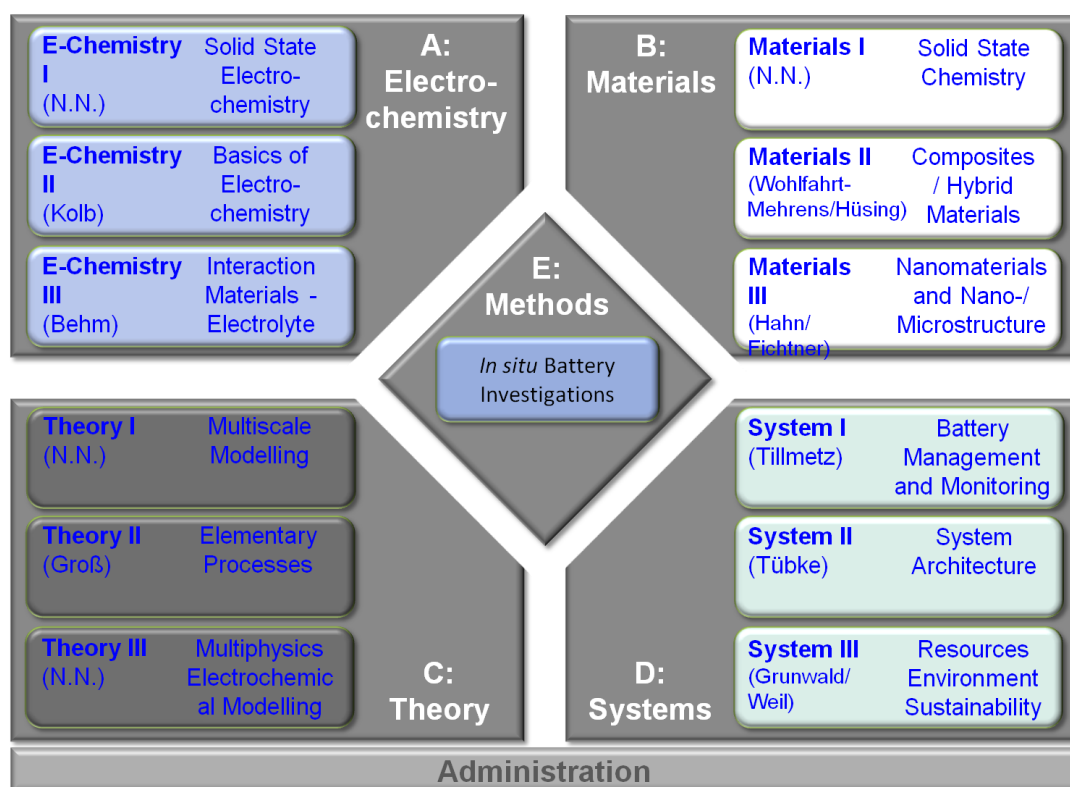


Figure 11: Structure of HIU<sup>6</sup>

System analytical investigations, also as a bridge between fundamental and more applied research, are conducted in Systems 3. One major objective is the cooperation with technology developers in order to incorporate sustainability issues in early development phases of new battery systems.

In this context technical system analyses is combined with life-cycle oriented ecological and economic system analysis. This approach aims at creating a deeper understanding of the technological requirements, ecological impacts and economic feasibility of prospective battery systems.

By embedding sustainability aspects into the early technology design phase, potential innovation risks can be identified prospectively and be minimized by appropriate measures. An essential task of System 3 is to provide orientational knowledge, e.g. on economic or ecological issues. Such knowledge can be used for decision-making (e.g. selection of promising anode materials).

Further activities prospectively examine potential value chains of selected future cell systems. On the one hand, the availability of resources for the production of both traction batteries and stationary batteries will be examined. In particular, a potentially restricted future access to strategically important raw materials is considered as a possible obstacle for the introduction and success of technological

<sup>6</sup> <http://www.hiu.kit.edu>

innovations. Currently the criticality of metals for emerging key technologies is an important topic, which finds a worldwide recognition. For instance, the restricted availability of rare earth metals (e.g. ytterbium, neodymium) is considered a critical issue for the production of super magnets (e.g. for wind-turbines). The criticality of other raw materials (e.g. lithium or platinum group metals) for electrochemical energy storage is a topic within HIU.

On the other hand, there is a focus on recyclability of electrochemical energy storage systems. Due to technical and economic reasons, current recycling technologies for batteries (which are still under development) do not recover all materials of the battery cells (e.g. lithium). It is planned to develop a roadmap for new battery chemistries, which will help to determine the technical, economic and environmental obstacles and identify ways to overcome these barriers. In this context it has to be analysed, whether the recycling technologies (e.g. for traction batteries) that are currently under development, are also suitable for the future cell systems developed by HIU, or whether new or adjusted recycling technologies must be developed, which would imply further economic and environmental effects.

In cooperation with the Helmholtz Portfolio project it is planned to develop economic models for distinct application fields, to analyse in a prospective manner, the potential cost performance of a new cell system, which are still under investigation, to identify promising applications and also to suggest optimization targets regarding the aimed application field. Behind this approach stands the idea, to support the development of suitable performance (for a specific application) and only to a less extend high performance.

### **3.1.2 Autosupercap**

Autosupercap is an EU funded project in the FP7<sup>7</sup> Initiative. In this project, a multidisciplinary consortium of research organisations, highly experienced industrialists, and highly active SMEs<sup>8</sup> is assembled to develop a new generation of supercapacitors (also called double layer capacitors). As a result, the consortium is aiming at developing supercapacitors of both high power and (much more important) high energy density. A high energy density would enable the application of the capacitor technology in hybrid and full electric vehicles.

In electric vehicles supercapacitors are essential for delivering power in the acceleration phase, which is a considerable proportion of a driving cycle, as well as to recover energy during braking which is also recommended for a sustainable energy and power system of a modern vehicle. High power and

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<sup>7</sup> Seventh Framework Programme (2007-2013)

<sup>8</sup> Small and Medium Size companies

sufficient energy density (per kilogram) are required for both the performance of the power system but also to reduce the requested weight of supercapacitors<sup>9</sup>.

The proposed objectives of the Autosupercap project are:

- tenfold increase of current maximum energy density while maintaining high power density. More specifically, binary carbon structure electrodes are targeted to have an energy density of more than 25 Wh/hkg and a power density of 25 kW/kg.
- multicriteria selection of the best supercapacitor cells for further scale up and fabrication of one or more supercapacitor test banks. The selection criteria will be apart from the power and energy density performance, also a cost level of 10€/kW for large scale commercial production and ecological aspects.
- simulation of real automotive requirements. Testing of supercapacitor banks on a test rig.
- Conduction of an economic and ecological life-cycle-analysis of the most promising supercapacitors for their applications in electric vehicles to assess the business case, economic and environmental sustainability.

The objectives exhibit, that system analysis is not only used to evaluate finally the developed supercapacitors, but also within the development phase itself, to identify the most promising capacitor test systems. For the realization of the technical performance improvement different kinds of nano materials will be used. The toxicity of nano materials is still a controversial topic with no final results. Therefore also in addition to LCA the nano particle fate along the life cycle of a capacitor will be investigated, in order to fulfil the precautionary principles (Weil 2011, Weil et al. 2012).

### **3.1.3 Portfolio**

The Portfolio project “Electrochemical energy storage systems – reliability and system integration” has the aim to identify various requirements on electrochemical energy storage technologies within diverse mobile and stationary applications for a specific research and development within multiple levels. This includes a system level view as well as a cell and material level view, regarding the integration and combination of future propulsion systems, entire storage systems with an increased energy density, electrodes, electrolytes or cells. The management and the scientific assessment of the topics are highly complex and should be seen as a long term interdisciplinary challenge. The expertise for this project is provided by the members of Helmholtz association (e.g. Karlsruhe Institute of Technology (KIT), German Aerospace Center (DLR), Research Center Jülich (FZJ)) as well as external partners (RWTH Aachen, TU München etc.) with scientists of multiple areas including inter

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<sup>9</sup> <http://autosupercap.eps.surrey.ac.uk>

alia diverse engineering fields, economics, social sciences and chemistry (Helmholtz Gesellschaft 2011). An overview about the focus areas and multiple level approach of the Helmholtz-Portfolio project are given in Figure 12.

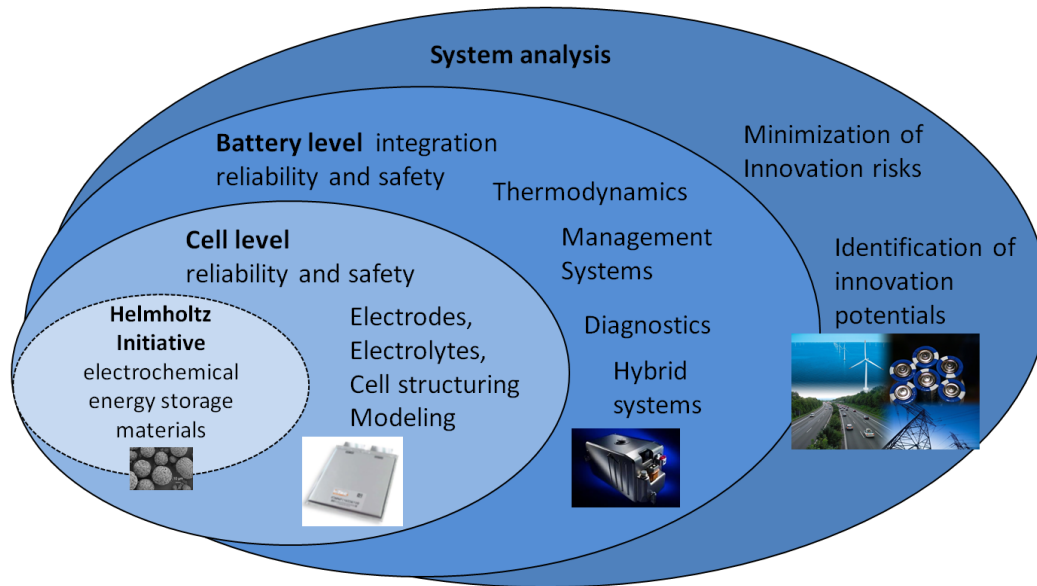


Figure 12: Focus areas within the Helmholtz- Initiative and Portfolio project respectively (Helmholtz Gesellschaft 2011)

The approach of the Portfolio project focusses on future battery systems (so called 4th generation batteries) whose properties are defined by system requirements of different application fields. This approach helps to define the most suitable battery specifications as well as the related research and development activities. The holistic system level perspective has the aim to develop different techno-economic scenarios including different application fields with adequate assumptions inter alia based on the sublevels as shown levels in Figure 12.

Some scenarios include for example various aspects of the grid integration of electric vehicles and their use for electricity system purposes. Such scenarios include the possibility of demand side management through electric vehicles or the use of vehicle to grid systems (V2G - bidirectional connected vehicle able to feedback electricity into the grid). First calculations and system modelling approaches showed that there are interesting opportunities in the German market for such systems but also that current battery systems are still one of the main challenges for such applications (e.g. due to low cycle stability etc.) (Fournier et al 2013). Currently available battery systems have a fairly low energy density coupled with comparatively high weight. This has a significant adverse impact on the range of an electric propulsion system. However, the battery is predicted to continue to constitute a

significant cost component in the manufacturing of electric vehicles in the long run. Lithium-Ion batteries of various types (cobalt, nickel, manganese, iron, and titanate) are currently considered to be the highest potential storage technology for mobile applications and are analysed and tested within the Portfolio project. Also promising new material combinations as lithium-sulphur or lithium air systems which could provide a massive energy density increase in the future are researched by the DLR and supported by a constructive technology assessment and system analysis.

As presented, the portfolio approach includes a broad system analysis with scenario development, safe electrodes development, to minimize innovation risks and identify innovation potentials on all levels and to improve market success of selected electrochemical energy storage technologies. Further aims are to develop new innovative solutions and facilitate the integration to existing technical and economic systems for a successful mobility and energy transition in Germany. The approach includes the use of scenario analysis of application possibilities, integration possibilities of battery systems, techno-economic comparisons of different energy storage possibilities as well as prospective life cycle assessments (Helmholtz Gesellschaft 2011). The multi perspective project outcomes can be used as a base for future research policy decisions or to estimate to a certain degree the importance of a certain development for the economy including export possibilities.

## **3.2 The Mobi-E**

This sub-chapter studies the decision making process of Mobi-E, the Portuguese e-mobility programme centred on the construction of a public charging network for Electric Vehicles (EVs). The network consisted on public parking slots spread around the country where consumers can charge their EV and conduct software operations regarding charging features. The study was based on a combination of methodologies which included literature research, analysis of official documents, a questionnaire and ten semi-structured interviews to relevant policy makers.

### **3.2.1 National ambitions**

A central question to develop nations is how to use technology to catch the economic frontrunners. In catching up economies, a frequent strategy is to create conditions to develop new industries. Accordingly, the Portuguese government decided that building an infrastructure to charge future vehicles was an effort that could promote development of its economy. Furthermore, the ambitious aims of the Mobi-E project help explain the use of technology to catch up with the most advanced economies. These aims reflected the idea that the Portuguese government could use technology as an opportunity to leapfrog the development steps that others needed to take to become prosperous.

The aims of the Mobi-E were considered ambitious for at least eight main reasons. First, it can be said that installing 340 public chargers and having 1300 installed in around Portugal in 2012 was an ambitious governmental push. In fact, the number of EVs was very low for such a supply of energy, with only 193 cars driving in 2011 and around 300 electric vehicles in 2012. But most importantly, their energy consumption was equivalent to only 11 vehicles. In fact, only 4% of the electric vehicle fleet charged their batteries using the public charging infrastructure (CI4, line 212-214). The remaining 96% charged privately and relatively inexpensively at a cost around 1.3 €/day (equivalent to 39 €/month) (CI4, line 220-225). Second, Portugal designed and implemented a programme to be “the most advanced programme for electric mobility in the world” (Pinto et al. 2010, p.1). The programme included “strong incentives to electric vehicles acquisition and operation, clearly boosting early adopters” (p.1). However, as mentioned the incentives were not sufficient to increase sales. Third, Mobi-E was conceived as a free-market consumers’ experience. It had the goal of “attracting private investors and benefiting the users, promoting a fast expansion of the system” (Pinto et al. 2010, p.1). However, neither investors appeared nor the benefits addressed the expected audience of user. In fact, a Delphi study on the Portuguese automotive sector held in 2004 concluded that the future situation that referred 50% of passenger automobile vehicles have systems of hybrid propulsion (electrical and gasoline or diesel fuel) would only take place on the very-long range according to the expert’s estimation (Moniz & Paulos 2008:6). That would mean some scepticism from the side of experts. Fourth, the Mobi-E aims were coupled with the idea of using clean energy produced after a strong governmental investment in renewables<sup>10</sup>. From the governmental point of view, it was sound to couple the production of renewable energy with the mobility needs of the Portuguese, thus reducing emissions and particularly its oil-import dependency. In this sense, the idea of leapfrogging development was present in the political discourse and coupled with the use of clean energy resulting from the governmental investment. However, this idealistic view masked the nature of a political sophisticated discourse that used technology as a mean to attain and maintain power. In fact, the effects of having a critical number of EVs using renewables could only be attained at least a decade after the governmental investments in energy were concluded. Therefore, critics sustained that at least for this generation of politicians “the technology is not really a way to modernize society, but to conquer and retain power” (I7, line 397-399). To conclude, it can be said that the coupling of clean and oil-free energies with the e-car was only a mirage with too many long-term variables to be possible. Fifth, the Mobi-E business model was also aspiring to be “first nationwide recharging network operating in the world” (Pinto et al. 2010, p.8). It granted universal access to any cars and batteries manufacturers, electricity retailers and recharging network operators. Furthermore, the model offered full interoperability and integration of all stakeholders, integration of information, energy and

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<sup>10</sup> In fact, Portugal was the third biggest producer of energy from renewable sources in the EU-27, in 2011 (Eurostat, 25/Apr/2013). It can be said that there were significant investments in hydropower (particular in the past) and also in wind and solar energy production. The country invested significantly in renewable sources of energy, and was able to generate 44% of the energy from those sources (Beltramello 2012).



financial flows through a managing authority and low initial investment costs<sup>11</sup> (Pinto et al. 2010, p.8-9). Sixth, the Mobi-E programme was also very ambitious in its socio-economic goals. The project expected to have a “significant economic impact, creating wealth (€3 billion of expected investment) and employment (6000 new jobs expected)” (Pinto et al. 2010, p.5, citing the National Energy Strategy 2020). However, neither the sales resulting from the project neither the number of jobs created come near this ambitious predictions. Seventh, the authors claimed that the project could “induce a more flat energy demand throughout the whole day” with a large number of electric vehicles (Pinto et al. 2010, p.5). However, several technical constraints with batteries need to be overcome to be able to flatten energy demands in the grid. Eight and last, the Portuguese decision makers included a pushed for the creation of an international observatory on electric mobility, and at the European level for regulations, norms, fiscal measures, CO2 reductions policies and a R&D and innovation agenda on batteries and integration with power grids. Most of these measures either failed to materialize or are still on the political agenda at supra-national level.

In parallel to the governmental setting, in 2008 the Mobi-E was unfolding. The research conducted for this work revealed that one group concurred in the elaboration of the Portuguese e-mobility policies, and centred the Mobi-E project on the hardware and software to charge and control the e-car (Boavida 2011). The group was composed by several companies, and was led by Inteli (a consultancy company associated with the Institute for SMEs<sup>12</sup> of Ministry of Economy), which was in charge of the Mobi-E concept and model. Other companies included the EDP group - the public energy utility, in charge of the integration with the grid; CEIIA<sup>13</sup> - a public-funded technology centre who developed an e-car prototype, part of the Inteli group, supported by the Ministry of Economy and in charge of the Mobi-E vehicles; Siemens, Efacec and Martifer – three technology companies, all dealing with the charging solution; and Critical and Novabase – two information technology (IT) companies, in charge of the IT solution.

The Mobi-E project was a partnership between the prime-minister and Inteli. But, several sources described that the initial idea of Mobi-E originated in the leader of the consultancy Inteli, as well as a software company Novabase (PI9 and CI7). Later the German consultancy group Roland Berger elaborated a detailed and prescribed report on electric mobility and specific features for public charging stations in Portugal (CI7, line 148-155 and Roland Berger 2009). However, the subcontracted Roland Berger was not very cautious in advising the Portuguese government, given the small fleet of EVs in Portugal in 2012 (e.g. around 300 and only 11 publicly charges per day). In fact, the consultancy strategy company forecasted a potential market of 180000 EV in 2020, with 25000 slow charging points and 560 fast (Roland Berger 2009). Furthermore, Roland Berger (2009) prediction were probably a result of their considerations. In their study, the company calculated that EVs were

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<sup>11</sup> Parallel to the Mobi-E project, other companies have their own small private charging systems, such as Brisa (a transport infrastructure company) and Galp (an oil and gas firm).

<sup>12</sup> Small and Medium Size companies

<sup>13</sup> Centro de Excelência e Inovação para a Indústria Automóvel

11% more competitive than normal internal combustion engines to private owners and 12% to companies.

The public powerhouse EDP also had an interest on being in the consortium leading the Mobi-E. In fact, Mobi-E chargers represented a business opportunity to obtain a new market, with a very low investment and risk, as well as an opportunity to be connected to an advanced technology process. First, according to an interviewee one electric car represents roughly the equivalent to one average client in Portugal<sup>14</sup> (CI4, line 44-47). Second, EDP had no initial financial investment, but only the cost to maintain the existing infrastructure (around 600 000€/year<sup>15</sup>) (CI4, line 66). Moreover, the formerly public energy provider EDP offered free charging of batteries between 2009 and 2011. Third, EDP presently controls and manages the Mobi-E system.

The programme had, however, some significant problems. First, some observers referred to governmental and consultants' attitude in 2009 as "euphoric". Despite the absence of successful full electrics in the beginning of 2010, decision makers believed that the massive introduction of electric vehicles was a consolidated trend, according to several sources. In fact, in a first meeting with the government and its consultants in 2009, other stakeholders were boldly told that "90% of the sales in 2020 will be electric cars", despite other totally different independent forecasts (CI8, line 440-462). The state of euphoria around the preparations for the coming e-cars can partially explain accusations of wrong doing. In fact, some critics claimed that the decision was also made to benefit the former public electric utility EDP, through the design of a business model to maintain its prominence in future energy markets (I7, line 153-159; CI7, line 49 and 102)). However, it seems more plausible that in an euphoric state of affairs, considerations regarding the immediate deploy of electricity would reigned among decision makers. Despite other claims, only the public powerhouse EDP could, at the time, promptly supply electric power. Second, the project also had a strong focus on electric cars, despite suggestions of complementary strategies. For example, one analyst revealed that the Mobi-E project was excessively focused on the e-car, leaving aside electric scooters, electric bicycles and other sharing systems that could enable the use of the public infrastructure (CI7 line 124-128 and I7 line 42). Interviews revealed the narrow focus on the electric car, rather than on mobility was promoted both by the Prime Minister cabinet in a "relatively centralized way" (I9, line 318-319), and by Inteli - the leading company that won the consortium (I7, line 46-47). The later company had an interest in CEIIA – a prototype producer of an e-car. Third, some analysts considered that the Mobi-E should be oriented towards companies' fleets. Instead, the government tried to convince Portuguese consumers and voters to buy electrical vehicles (CI7, line 120-121). The state financed an innovation project and its development between companies. After, companies refrained themselves because they felt they could not control it and the project was just a political show-off to someone else (CI7, line 229-232). Fourth, some critics supported the view that the Mobi-E project should have been privately led, instead of

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<sup>14</sup> If it does 10000 Km/year

<sup>15</sup> According to 2012 costs

steered by the government with an investment of ~15 million euros (CI7, line 115-118; E-move 2013). However, most analysts agree that Mobi-E can be reasoned within an interactive innovation model, where the government can act as an enabling actor and catalyst of regime changes, without any guarantee of success (Kemp et al. 1998). Fourth, the car cable for public charging is very costly and its use is unsecured, forcing consumers to run the risk of robbery during charging periods, according to an interviewee (CI5, line 22). An internal cable fixed to the charging station should have been included in its design. Furthermore, there are small but growing signs of law infringement, with non-electric vehicles parking in the public charging points (CI7, line 130-131; (E-move 2013)).

To conclude, most analysts supported the idea that electric mobility will be further developed in the future, even though it was just a political project. What is still not clear, nevertheless, is when will EVs finally entered the Portuguese car market to use the public infrastructure.

### **3.2.2 “Studying” after the decision**

The research revealed that the decision making process of Mobi-E was dynamic. When the proposal reached the Prime-minister cabinet, there was already a consortium of companies in-line to support the political decision and to implement the project (I7, line 207-209). An interviewee reported that the decision was based not on the technological effect of the policy, but rather on its political and social impact (I9, line 84-86 and PI9). The central argument used to justify the decision was that “the lack of a recharging infrastructure deters the acquisition of electric vehicles” (Pinto et al. 2010, p.15). As expected in this context, there was also the need to provide some rationale to the decision. In fact, several sources revealed that some studies were elaborated *a posteriori* to support the decision that was already taken (I7, line 88) (I9, line 74-75). Furthermore, the findings revealed that technical indicators were seek only after the decision was made (I9, line 88-89; and questionnaires).

In Portugal, the effort to elaborate studies to justify *a posteriori* the decision taken to promote electric cars was naturally hopeless. In fact, governmental forecasts needed to be inevitably too optimistic to support such a decision. This need for optimism not only rose from the dependence of a technology being tested in Japan, but also from the lack of interest from the few existent automakers, the meagre industrial base existent in the country and the small-scale of the Portuguese economy.

The conclusions of the government study and seek indicators intended to confirm the political decision. In fact, according to the 2010 forecast of the coordinator of the office for electric mobility, in 2020 Portugal intended to have 750 000 electric vehicles (Gomes 2010:40). However, according to a scientific study by Paulo Santos in 2009, there would be almost 600 000 electric vehicles in 2020 in a “very” optimistic scenario (Santos 2009:40). Furthermore, according to the author Luís Gomes (2010),

the governmental forecast was very optimistic because it represented 80% of the sales in 2020 (considering a sales growth rate of 1%). In his study the author forecasted an optimistic scenario with a penetration rate of 50%, predicting only 322 027 electric vehicles in 2020 (Gomes 2010:40-41). In addition, the idea that the governmental study only intended to confirm the decision is also in line with previous findings (Boavida 2011).

To conclude, several sources agree that Mobi-E was a decision rather than a constructed policy. In fact, several lobbyists concurred to the Prime-Minister decision of having the e-car, regardless of the conclusions of studies. Furthermore, the political decision did not include a reflexive exercise to either elaborate on a rational choice related to mobility in the country nor to energy policy. In the end, it can be said that Mobi-E was a ~15 million euros political project led by the will of the former prime-minister and a lobby. The programme needs to be re-evaluated under an at least an economic rationale.

### **3.2.3 Impacts**

The analysis revealed a few elements of knowledge production. In fact, the academic and oriented research input and output were meagre for a governmental technology policy in a developed economy. Furthermore, as expected the links to industrial knowledge were also weak.

The links with the previous existent and future e-mobility community were also weak. A small community existed around a state funded civil association and inventors of e-vehicles. However, they were both disregards in the Mobi-E programme.

There are some elements to conclude that users' perceptions were disregarded in the Mobi-E programme, and might partially explain its failure. According to Schippl & Puhe (2012, p.36) they play a crucial role regarding the success and failure of transport related innovations. During this research (Boavida 2011), it was not possible to detect any element of inquiry of users' perceptions until March 2010. By then a small quantitative study was carried out for the national energy certification and quality control agency, regarding individuals' acquisition intentions and the localization of charging points in Portugal (dataE 2010).

### **3.2.4 Conclusions**

In summary, it can be said that the Mobi-E was a display of technology might, as a way to attain and maintain power under the idea of leapfrogging development in Portugal. The novelty of this programme is that the government wanted to address all Portuguese with a message based on technology, regardless any proper internal or external studies or reflexions. The idea was neither to involved old fans of e-mobility, nor to gather new comers. The government mainly wanted to send a

message to society of how powerful technology can be to conquer development and well-being. However, the governmental message was blocked, as the effects of the financial and economic crisis severely hit Portugal after the end of 2008 and sales never grew. Having 1300 empty charging point spread around the country is hardly a pleasant statement for public investment in technology, for better mobility or improved energy consumption. There were news of a few charging points destroyed or not working properly, and reports of illegal parking in charging points. Nevertheless, given the severe 2013 crisis and the restricted number of anti-Mobi-E news, it can be said that there was not yet a social backlash and that electric mobility is for now suspended.

### **3.3 Projects for the STOA panel of the European parliament**

In this subchapter, two projects carried out for the STOA panel of the European parliament will be illustrated. The focus is on the approach applied as well as on results of special relevance for the topic of e-mobility. One project was on “Eco-efficient Transport” in general, the other on “Urban Transport”. Both projects aimed at producing policy-relevant insights into potential future developments in the transport sector. Both projects explicitly applied a systemic and prospective approach on developments in the transport system, whereas the main objectives and the corresponding methodological approach were slightly different. It was illustrated in the introduction to this paper that a systemic perspective is needed for understanding the potentials of e-mobility, taking into account different elements such as batteries and vehicles, infrastructures, new business models and also behaviour. Further, the perceptions and attitudes of stakeholders are relevant for innovation processes and for policy-making in a certain field. As regards content, for both projects e-mobility was a key-technology since it is perceived as one of the most important approaches for making the transport system more eco-efficient and, furthermore, urban transport is expected to become one of the main areas for its application.

#### **3.3.1 Eco-efficient transport**

The project on Eco-efficient Transport applied a foresight-related approach, with scenario building and stakeholder assessment of scenarios (regarding desirability and feasibility of measures) as methodological core elements. It tried to apply a broad perspective on the transport system, developing different scenarios. The scenario approach is based on the conceptualisation of eco-efficient transport that was used for this project, and that assumed that eco-efficient transport encompasses all approaches that help to reduce the ecological footprint of transport-related activities. The point of reference has

been the amount of resources needed to fulfil a certain purpose (work, social contacts, production or purchase of a good; economic growth, etc.), and a wide range of technologies and concepts supporting eco-efficient transport – already available ones and others that are emerging – have been analysed.

In order to make the results more tangible, the project made use of qualitative scenario-building supported by quantitative modelling. Keeping the above conceptualization of eco-efficiency in mind, the different scenarios focused on three basic strategies for achieving eco-efficiency in the transport sector: First, the individual transport modes/vehicles can be made cleaner (cleaner modes scenario). This involves approaches such as using cleaner fuels and propulsion technologies, lightweight construction, efficient design of vehicles etc. Also eco-efficient driving and corresponding training belong to this category. Second, transport can be shifted to more efficient modes (modal shift scenario). This includes, for example, a shift from road to rail or, in the urban passenger sector, a shift from motorized modes to cycling. Third and last, transport volumes can be reduced (reduced transport volume growth scenario). This can be done by substituting trips, for example by tele-working or video-conferencing. Further, this can be achieved by reducing the length of trips. The latter approaches can be the result of a land-use planning leading towards a city of short distance (decentralized concentration).

Within the project, electric mobility has been mainly ranged in the first scenario on cleaner modes, e.g. by the thesis “More than half of the passenger cars sold per year will be battery electric vehicles with driving ranges of 400–500 km” derived from the scenario storyline. If electric mobility is regarded as ‘electrifying the automobile’, this is fully consistent with the framing of the first scenario, in which the same (but cleaner) modes are employed by the users – in contrast to the second and the third scenario, where users use different transport modes or where users and goods have different origins and destinations, respectively. However, the stakeholder consultation conducted during the project clearly showed that such a cleaner modes approach can be no more than a building block of an eco-efficient transport future. Rather, different approaches have to be combined because transport technologies, modal shares and dynamic mobility behaviour of users and customers show strong interdependencies. Consistently, stakeholders assessed the barrier of uncoordinated action of the various actors in the transport sector among the most important factors that could impede a development towards eco-efficient transport.

### **3.3.2 Urban Transport**

As its title already suggests, the project on Urban Transport had a slightly different focus. The idea of the project was to get a better understanding of promising innovation pathways towards more sustainable urban transport. Of course, e-mobility is one important pathway in this context. For making a holistic perspective operational in this project in a transparent way, the transport system was

explicitly divided into different segments: visions and paradigms, mobility patterns, transport policies, business models, and technology and infrastructure. Then developments in the segments as well as interactions between them were analysed.

The project revealed that developments in all segments have their influence on the future of urban transport and also on the future of approaches such as e-mobility. In particular developments in the field of business models, ICT and mobility patterns are crucial for the role that e-mobility will play in urban transport. Focussing on mobility patterns, changing attitudes and preferences, experiences and behaviour of transport users have been taken into explicit consideration within this project. Besides, the need for a better understanding of people's travel demands and user behaviour, raised during the stakeholder consultation in the Eco-efficient Transport project as well, has also been noticed by the transport industry. The industry expects profit from a better understanding of the transport needs and behaviour in order to foster changes, which shows the importance of taking this perspective into account.

For electric mobility, user behaviour and attitude do not only come into play during the purchase of electric vehicles, but also for daily mobility behaviour habits and routines are of crucial importance and will strongly influence the success or the failure of a transition towards electric mobility. For example, results from several interview meetings conducted within the Urban Transport project indicate that younger people in urban areas show a more pragmatic attitude towards cars and car ownership and they use the car significantly less compared to the same age group ten years ago. Car ownership and kilometres driven decrease in this age group in many industrialised countries. On the other hand the generation 60+ has a more active lifestyle than the generation before which is also expressed in an increase in private motorised transport usage. Ultimately, transport-related choices are more than rational economic decisions; decisions of where to go by which means of transport essentially depend on attitudes, perceptions, norms and values.

## **4. Conclusions and discussion**

### **4.1 System analysis of new battery systems for mobile and stationary applications**

The development, production, use, profitability and disposal of electrochemical energy storage technologies will have a major importance for a sustainable development and must be co-considered in the socio-technical conversion of our mobility as well as energy transition process. All the presented projects offer a broad system insight on different levels for different relevant electrochemical energy storage systems for a mobility (and energy) transition in Germany. The single projects cover all areas from basic (HIU) to applied research (AutoSupercap and Portfolio).

Within HIU technical system analyses of electrochemical energy storage systems is combined with life-cycle oriented ecological and economic system analysis to create a deeper understanding of the technological requirements, ecological impacts and economic feasibility of prospective battery systems as Li-Sulfur or Li-Air.

The project Autosupercap is focusing on supercapacitors (also called double layer capacitors) with the aim to evaluate developed supercapacitors, but also within the development phase itself, to identify the most promising capacitor test systems. Especially the toxicity of nano materials is still a controversial topic with no final results which is assessed by a LCA<sup>16</sup> of the nano particle fate along the life cycle of a capacitor.

The approach of the Portfolio project also focusses on future battery systems (so called 4th generation batteries) whose properties are defined by system requirements of different application fields. This approach helps to define the most suitable battery specifications as well as the related research and development activities.

The projects overlap in some areas, but approaches are different and could lead to (to a certain degree) different results and can be considered as a consolidation of advanced research in this important area to support the socio-technological system transition in the mobility sector. However, a common target of all projects is the idea of shaping technology by an early reflection of possible later mismatches, wrong investments, possible social conflicts, and environmental impacts as well as to identify the seamless web of related highly heterogenic factors and different stakeholders (partners from the

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<sup>16</sup> Life Cycle Assessment



industry, end users or politicians) regarding battery systems which are embedded in the socio-technological system of transport and energy. The multi perspective results of the different projects offer the possibility to provide a solid base for future research policy decisions, to estimate to a certain degree the importance of a certain development for the economy including export possibilities. The activities in the field of chemical energy storage some of them have been presented in this paper, show how important this technology is for the further development of a sustainable mobility development as well as energy supply.

## **4.2 Mobi-E**

The Mobi-E programme fell short of the initial expectations. The policy makers' discourse inspired a sense of innovation, sublime and the hope that technology awe would help to solve the problems associated with transport, economy and pollution. Behind the rhetoric, however, the Mobi-E project left behind an integration of the e-car in an overarching concept of sustainable mobility, the need to change human behaviour and the dynamics of users' perceptions. Several other significant problems concurred to the lack of consumers' mobilization around the Mobi-E project. Among them were the financial and economic national crisis and the inability to involve key communities with electric mobility.

Policy-makers should play a new role and act as enabling actors and catalysts. It can be said that the Portuguese government played his part in the game, perhaps in a voluntaristic and sometimes naïf manner. There was not a clear effort to separate lobby groups from the technology policy. However, there is an element of luck involved in technology policies there is never a guarantee of success for technology change. In fact, circumstances are volatile and may create a situation where the technology becomes less attractive and technological promises may never materialize. Presently, there is still the hope that the e-car may materialize in a not so distant future. However, according to analysts EVs will take more than 10 years to reach the mass markets, and possibly hybrids technologies will be the next technological regime. Although involved initially in a mist of euphoria and later in fierce realism, the Mobi-E consisted in a choice of a technology, much more than an option for mobility or energy policy in Portugal. In reality, for the foreseeable future the public charging infrastructure will always be used in a sub-optimal way. In the end, the Portuguese Mobi-E presented a push towards alignment of actors for a sociotechnical transition, but fell short on attaining it.

### **4.3 Projects for the STOA panel of the European parliament**

The STOA project on Eco-efficient transport shows that e-mobility can only be part of a patchwork of solutions that bring the transport system towards eco-efficiency and sustainability. The potential of e-mobility is impressive and the electrification of road transport is well worth to be strived for. However, cleaner car transport alone will not be sufficient to solve those problems that the transport system is facing today. The challenges that are offered today will not be met by cleaner car transport alone; e.g., substituting the existing car fleet with an electric one will not help with congestion in densely populated areas. Within the project, and underpinning this problem, stakeholders as well agreed that pure technology will not be the key.

Instead, the shift towards eco-efficient transport and e-mobility requires a much more systemic perspective. It is not only about the electric equipment of vehicles and charging infrastructure, but far beyond, all actors affected by this transition have to be considered. This does not only include all kinds of technology developers, but as well stakeholders within and outside the transport system, policy-makers at all relevant levels, and actual users. Without taking into account and balancing the perspectives and requirements of all these, the aspired transition is likely to fail and it will likely fall short of fulfilling the expectations placed into e-mobility. This balancing requires mutual understanding, consultation and cooperation.

Users do particularly matter. The best technological solution will fail if it is not accepted by the users. Specifically in the urban transport sector, users' complex behavioural patterns are not static, but change constantly. The results from the STOA project on Urban transport exemplarily show the changes in attitudes and preferences, experiences, and behaviour of people. These changes of people's mobility patterns crucially affect the usage of the transport system and they will challenge new technologies that are introduced in the transport system, aiming at its fundamental change. New operational requirements and constraints, and new opportunities will not only challenge manufacturers and suppliers, infrastructure operators, and policy-makers, but users as well. Therefore, stakeholders during the consultation in the Eco-efficient transport project explicitly claimed that transportation should be planned, developed and implemented "closer to the customers". This is not only valid for eco-efficient approaches in the transport sector in general, but specifically for e-mobility, where all the mentioned systemic changes will need to take place and will need to be accepted by the demand side.

## **4.4 Discussion**

There is a pressing need to find both analytical and governance approaches that are able to handle the growing complexity in transport systems, integrate new and old stakeholders, and provide efficient solutions for the mobility in societies. In particular, the automotive industry needs to take holistic approach to cope with the e-mobility shift, because technology and economic solutions are but a part of the new equation. Other important issues to be taken into account include user acceptance, social implications, industrial dynamics, governance, control and power. Only in this way technology decisions can successfully meet the current and expected future needs of society and the automotive industry itself (Moniz and Paulos 2008; Moniz et al 2002; Schippl and Fleischer 2012).

Technology assessment provides an analytical framework that is designed in order to deal with such complex problems. Bringing together the realms of mere technological development, implementers, users, and societal framework conditions, technology assessment delivers the required systemic perspective on future developments. In doing so, technology assessment can not only point at trouble and negative side-effects, but, in contrast, contribute proactively to more robust solutions and approaches that circumvent obstacles and aim at the best possible solution from the beginning.

All presented projects have different research directions within the field of electric mobility which can be divided into technology, society and politics. Based on their directions the cases aimed to give supplementary information of their specific research direction. Nevertheless, there are several thematic crossovers between all projects presented leading to a synergetic technology assessment. This output results from the overlapping areas between the cases and can be used to first assess the extent of changes in the present socio-technical regime, as well as to extract standards and regulations, acceptance/risk analyses and behaviour changes that could be significant in the context of a transition towards electric mobility.

## **4.5 Outlook**

This work represents a first review of projects within the field of electric mobility to identify the different aims and provide an overview of Technology Assessment based research in this area. In a further step this review will identify knowledge synergies in order to provide a comprehensive system understanding, allowing it to derive adequate recommendations to assist policy, technology and society based decisions.

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